SOURCE ATO - Large Platform Autonomy in Urban Environments

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Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **03 AUG 2012**	2. REPORT TYPE **Briefing**	3. DATES COVERED **01-07-2012 to 01-08-2012**
4. TITLE AND SUBTITLE **Source ATO - Large Platform Autonomy in Urban Environments**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Joseph Knott; Dariusz Mikulski**		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC,6501 East Eleven Mile Rd,Warren,Mi,48397-5000**		8. PERFORMING ORGANIZATION REPORT NUMBER **#23229**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC, 6501 East Eleven Mile Rd, Warren, Mi, 48397-5000**		10. SPONSOR/MONITOR'S ACRONYM(S) **TARDEC**
		11. SPONSOR/MONITOR'S REPORT NUMBER(S) **#23229**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Submitted to 2012 NDIA Ground Vehicle Systems Engineering and Technology Symposium August 14-16 Troy, Michigan

14. ABSTRACT
The SOURCE large autonomous UGV system provides a valuable platform to advance the technology and methodology necessary to employ an increased use of UGV?s to satisfy Army missions.

15. SUBJECT TERMS
Safe Operations of Unmanned Systems for Reconnaissance in Complex Environments

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Public Release**	**33**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

ROBOTIC SYSTEMS

- **What is SOURCE?**
  - Safe Operations of Unmanned Systems for Reconnaissance in Complex Environments

- **Why is SOURCE important to the defense community?**
  - SOURCE continues to utilize and enhance the hardware and software developed under the BCTM Autonomous Navigation Systems (ANS) program.
  - SOURCE is integrating and evaluating a suite of lower-cost sensors on a T2 platform.

- **What is addressed in the presentation?**
  - Operational Concept
  - The Platform and Autonomy System
  - SOURCE Sensors, both full Mil Spec and Lower-Cost
  - System Capabilities
  - Testing

Operational Concept Video

- SOURCE UGVs are built on capable, base vehicles of different classes.
  - 9 Ton, Electric Hybrid, skid steer Platform (APD)
  - 4600lb, Jeep-based Platform (T2)
- A suite of multiple sensors and an advanced SOURCE Autonomy System (that leveraged technology from multiple DOD programs) are added to the SOURCE platforms to provide autonomous operation
  - Autonomy system has been exercised on a wide variety of other platforms during different phases of development
  - MTV family, Stryker, Crusher, Predator and commercial vehicles.

Predator

MULE

Crusher

LMTV

MTV

Stryker

F-450

SafeOps T2

APD

ROBOTIC SYSTEMS

- The SOURCE large autonomous UGV system provides a valuable platform to advance the technology and methodology necessary to employ an increased use of UGV's to satisfy Army missions.

  - Provides essential autonomous capabilities
    – Leader-Follower
    – Move-on-Route
    – Tele-operation
    – Remote Situational Awareness

  - Multi-modal, high resolution, all-digital sensors
    – Fused Color, Monochrome, LWIR, LADAR, MMWR sensor data
    – Support nighttime and daytime operations
    – MMWR provides early warning for approaching vehicles with high closing rates

  - COTS-based Multi-processor Computer System:
    – Mission planning algorithms perform missions employing tactical behaviors
    – Advanced local planning algorithms detect and avoid obstacles
    – Multiple CPU + GPU + FPGA modules for hardware acceleration

TARDEC developed Advanced Platform Demonstrator (APD)

LADAR + Stereo EOIR Imagers

GPS/INS Navigation System

Rear Facing EOIR Imager

Computing Hardware

Automotive Radar

Advanced Platform Demonstrator (APD)

NDIA — Michigan Chapter — National Defense Industrial Association

GVSETS

- Low Cost Sensors Integrated on SOURCE T2
  - Navigation Unit - RR N-120-F GPS/IRU
  - Scanning LADAR - VLCL
    - 100º x 40º FOV
    - Max Range: 100m
    - Integrated Imager, IMU and Data Processing
  - Stereo Video – ESO Stereo Module
    - Imagers: 1280x800, 30 frames/s
    - 60º x 40º FOV
    - Integrated stereo and image processing

- Building on key technology from SOURCE Enhanced Experiment

- Joint SOURCE IMOPAT Capstone Demo per TARDEC CONOPS

- Provides essential autonomous capabilities
  - Leader-Follower
  - Move-on-Route
  - Tele-operation
 - Remote Situational Awareness

TARDEC developed T2

Scanning LADAR: Very Low Cost LADAR (VLCL)

Stereo Video: ESO Stereo Module

Navigation Unit RR N-120-F GPS/IRU

Stereo Cameras

Automotive MMWR

T2 UGV Platform

- The Autonomy System, in addition to the sensor suite includes all of the software and algorithms necessary to autonomously operate the UGV to accomplish a mission based on operator objectives.

- Key Technologies
    - Automated extraction and intelligent interpretation of relevant(and often, subtle) information from multiple sources of data
    - Autonomy System fuses data from various sources to create an internal model of its surroundings
    - The UGV uses the internal model to plan its immediate actions given the higher-level mission planning and goals.

- Contains a diverse set of sensing technologies as well as the advanced autonomy system to interpret the sensor data
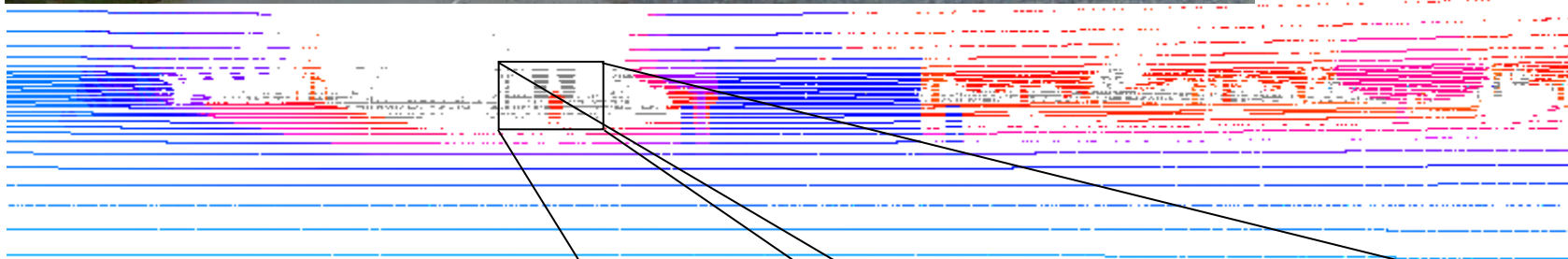   - No single sensor technology works well in all situations.
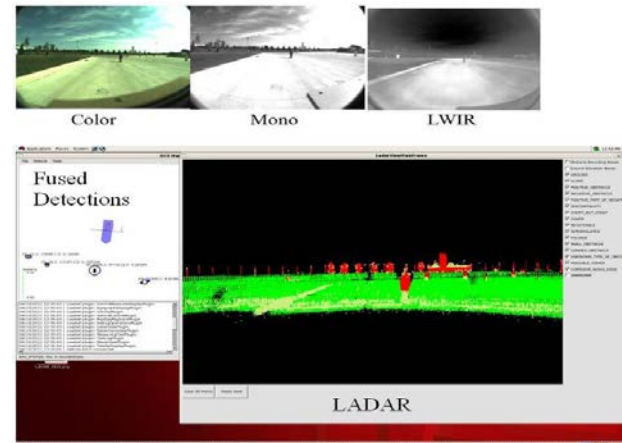
**SOURCE Data from Multiple Sensors Is Used To Interpret Its Surroundings**

Mannequin at 100 m

Mannequin height ~1.7 m

LADAR height ~ 1 m

Dry asphalt road surface

- Foveal scan is centered on mannequin

- Achieved ground returns at 80 Meters

- 86 pixels on mannequin

- More "pixels on target" than common, off the shelf systems

- Performance key to supporting higher speed operation
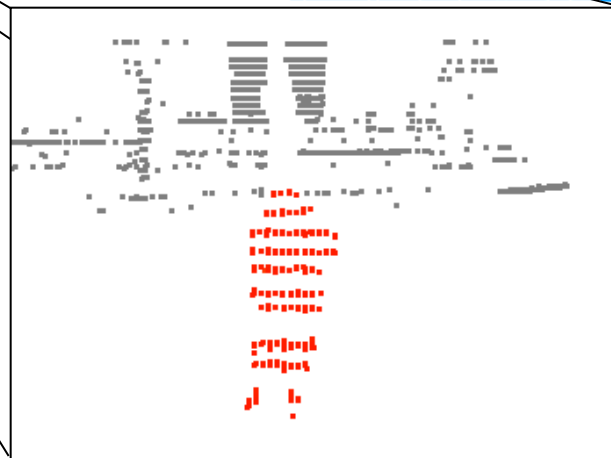
Functions:
- LADAR, Visible, IR, and monochrome stereo cameras for 3D imaging
- Autonomous driving, remote operations, detecting objects, terrain, ranging
- Supports SA
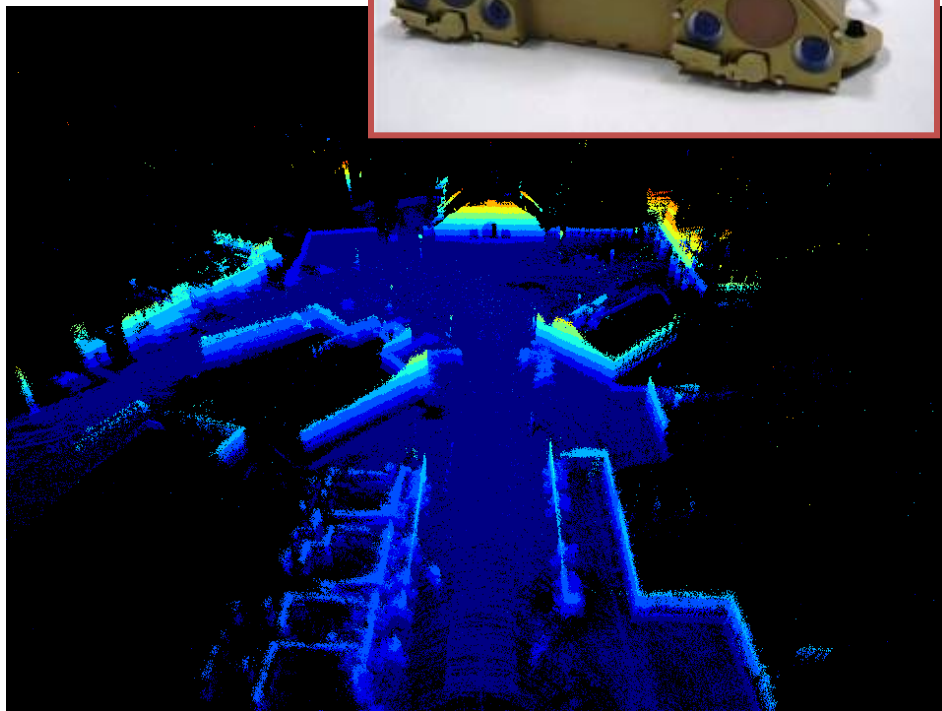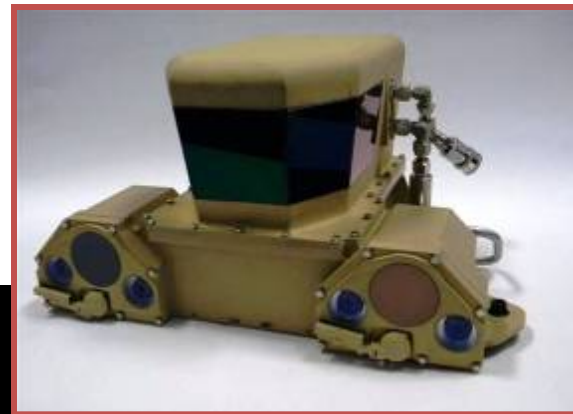

Performance:
LADAR
- Max. Range: 150m
- Field of View: 240°x37°
- Scan Rate: 1000 RPM azimuth
- Pixel Rate: 3 Mpixels/sec

Imagers
- Color   120°x90°   1280x960* 30 Frames/s
- Mono   120°x90°   1280x960* 30 Frames/s
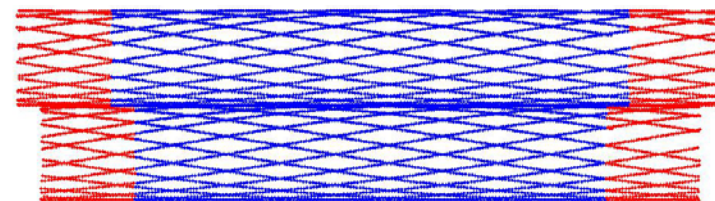- LWIR   120°x90°   1024x768* 30 Frames/s

Parameter	Baseline
Horizontal FOV	100+ deg
Vertical FOV	40 deg
Enc. Hor. Resolution	0.1 deg
Enc. Ver. Resolution	0.1 deg
Range Accuracy	1 cm
Min Range	1 m
Max Range	150 m (for 25% targets)
Size	134x117x112 mm
Weight	1.4 kg
Power	35.7 W (Peak) 33.2 (Avg.)
Scan Rate	5.25 Hz (full area)
Wavelength	905 nm

LADAR Scan Pattern

- A Low Cost Sensor System That Outputs Both A Detailed 3D Depth Image/Range Grid And A Per-point Terrain/Material Classification

ROBOTIC SYSTEMS

- SOURCE Stereo Module
- High Dynamic Range Color Imagers
  - Robust Operation Under Difficult Lighting Conditions
  - Operates Even With The Sun In the Image
- Stereo Module Includes Integrated Processing CPU Hardware
  - Offloads Perception Tasks from Autonomy Computing Hardware
- Human Detection Out To 25 Meters

Parameter	Baseline
Imagers:	Color 1280x800 High Dynamic Range USB Imagers
Horizontal FOV	65 deg
Vertical FOV	45 deg
Stereo Algorithm	SAD5 w/Post Filtering to Reduce Noise Integrated Stereo Processing Hardware
Stereo Resolution	Programmable: set to 640x480 (limited by USB interface)
Stereo Frame Rate	15 frames/s at 640x480
Stereo Baseline	9 inches

SOURCE Core Functionality	Features
Provide Core Navigation Support	• Position, Orientation, Velocity, Acceleration • Integrated GPS/INS/Wheel Odometry • Increased Accuracy Using Perception Sensor Data
Provide Remote Operation Support	• Low Latency, Compressed Video Data for Remote Operator • Teleoperation with Driving Aids
Provide Situation Awareness (SA) Support	• Provide Vehicle & Human Tracks • Provide Video Data for Interpretation by an Operator
Move-On-Route	• Detailed Route Planning based on a Mission Plan • Urban On Road and Off Road Operation • Safe Operation and Obstacle Avoidance based on Sensor Data • Pedestrian Detection/Avoidance • Vehicle Detection/Avoidance • Obey traffic rules and regulations
Vehicle Following (Convoy and Formation)	• Follow Path Determined by Leader Navigation State Data • Detect and Avoid Obstacles Based on Perception Data • Use Perception Sensor Data to Improve Following Accuracy
Dismount Following	• Follow Dismount Path • On Road, Urban Following and Off Road Following

SOURCE – Key Capabilities

- Move On Route
  - Autonomously Follow Operator Designated Plan
  - Operate In Complex Urban Surroundings
- Leader-Follower Operation
  - Follow Dismounted Warfighter
  - Follow Lead Vehicle or Warfighter in Vehicle
- Teleoperation and Supervised Autonomy
  - Operator Direct Control
  - Driving Aids to Help Remote Operator
  - Immediate Operator Override or System Requests Operator Intervention

- The SOURCE UGV Follows Specified Waypoint Plans
  - Multiple Waypoint Goals,
  - Speed Limits,
  - Corridor Limits Or Keep Out Zones Along The Planned Route
  - On Road Or Off Road Behavior
- Once Under Way, The SOURCE UGV Autonomously Performs The Move-On-Route With Little Or No Intervention By The Operator
  - Unless The UGV Cannot Find A Route To Achieve The Specified Goals.

- The SOURCE Autonomy System Maintains Safe Operation By Detecting And Avoiding Both Static And Moving Obstacles
    - The Autonomy System Detects And Predicts The Movement Of Pedestrians And Vehicles
    - Determines The Appropriate Action To Avoid Collision
- SOURCE Urban Behavior Includes Safe Operation On Known Roads Following Standard Rules Of The Road
    - Includes Knowledge Of And Safe Behavior For
        - Roads And Lanes
        - Intersections
        - Lane Directionality
        - Accounts For Other Vehicle Traffic And Pedestrian Motion
    - Current Phase Depends On Prior Road Network Data

- UGV Follows The Dismount's Route Rather Than Waypoint Plan
  - Using Sensing Equipment The Warfighter Has
    - Dismount Controller And Pedometer
  - Using UGV Perception Sensors (Under The Right Conditions)
- Supports Leader Switching Between Vehicle And Warfighter Leaders
- Supports Following A Dismounted Warfighter Switching From Movement On Foot To Boarding A Vehicle And Later Dismounting Again
- Supports Perceived Dismount Leader Position
  - Reports perceived position of dismount
  - Smart filtering of dismount leader position (similar functioning for either perceived or reported data)

- Dismount Controller
  - Hand Held

- Pedometer
  - Shoe Mounted

- SOURCE Includes An Optionally Enabled Smart Following Mode
  - Supports Urban Operation
- UGV Does Not Follow The Dismounted Warfighter's Path Exactly
- Instead, The UGV Follows The Warfighter By Following The Roads
- In This Way, The UGV Will Not Drive On The Sidewalk To Follow The Exact Path Of A Warfighter On A Sidewalk

Warfighter
On A Sidewalk

UGV Follows
The Warfighter
But Keeps To Road

Image For Illustration Purposes Only
- Not From An Actual Dismount-Follower Run

- ## SOURCE Autonomy System Provides Driving Aids For The Operator
  - Allows The Operator To Leverage Data From The Autonomy Systems Sensors And Perception Processing
  - For Example, Objects Detected With The LADAR, Stereo Vision Or Millimeter Wave RADAR
  - These Are In Addition To Standard Vehicle Information Such As Video, Speed, Heading, And Absolute Position

- ## Supports Close Interaction Between Operator Or Vehicle Driver And The UGV

- ## Supports Improved Remote Operation And Safety, Especially Under Poor Visibility Conditions

- The SOURCE Program is Based Around Three Major Experiments
  - Baseline Experiment – Sykesville (Jan 2011)
  - Enhanced Experiment – MOUT, with Soldiers (Aug 2011)
  - Capstone Experiment – MOUT, with Soldiers (Aug 2012)

- Key Goal is to Demonstrate SOURCE Autonomous Vehicle Capabilities while utilizing ANS and Lower-cost Technologies
  - Depends on Both ANS and non-ANS Technology Development

- Testing Will Focus on a Usable System for the Warfighter
  - Increasing Functionality at Each Experiment
  - Experiment 3 Includes Soldier Operations per CONOPS
  - Integrated with Other TARDEC Systems
  - IMOPAT, SUGV, etc.

- ## Integration of ANS onto GDRS T2
  - Build on ANS and SafeOps Expertise
- ## Sykesville Test Track (Jan 2011)
  - GDRS T2 with Integrated ANS
    - LIPM, IPMs and MEBB
  - Based on ANS Engineering Phase 15 (EP15) Early Software
    - In-process version on ANS EP15 Software
- ## Autonomous Operation on Roads
  - System and T2 Vehicle Response
  - Incorporate ANS Sensors and Software
  - Initial Integration of Traffic Planner and High Maneuverability Planner
  - Use of Prior Road Data
  - Initial Moving Obstacle Detection and Avoidance
    - Humans (Mannequins)

- Engineering Data Internal to the System are Logged During Experiment Runs as Well as Most Engineering Runs
  - ANS "high-level" status
  - Navigation Data
  - Vehicle Parameters
  - eTALIN status
  - System Config options
  - Hardware (MEBB) characteristics
  - Software version
  - ANS modes
- Logged Data Reviewed Offline to Analyze Software Execution in Detail
- Test Personnel Observations and Records are Also Saved

- ## Platform and Software Integration and Shakeout
  - Integration of ANS Surrogate Computer and Sensors onto APD platform
    - Multiple Field Integration Events on APD
  - Integration with Battle Command System and WMI
- ## Autonomy Development Focus
  - Moving Objects Detection/Tracking
    - Vehicle and Pedestrians
    - Multiple Sensors (LADAR and Stereo Vision)
  - Road Network Planner (Traffic Planner)
    - Static and Moving Obstacle Avoidance
    - Registration to Prior Data for Improved Navigation
  - Off Road Planner
  - Platform Control In Tight Spaces
 - Overhangs/Slope/Terrain Operation

- The Enhanced Experiment, the second SOURCE experiment, was a data collection event intended to establish the capabilities of the ANS sensors and software integrated onto the APD vehicle.

- The Enhanced Experiment grew on the capabilities established in the Baseline Experiment.

- SOURCE Enhanced Experiment shake out activities took place from October 17th to November 2nd, 2011 in Camp Lejeune, North Carolina.

- Official data collection for the experiment was conducted in Camp Lejeune from November 5th to November 8th, 2011.

- The official runs for record were conducted utilizing the APD as the test platform.

- Human Detection/Tracking/Avoidance is the primary focus in the SOURCE experiment. Detect and avoid stationary and moving mannequins near buildings in a complex MOUT site
- Multiple Sensors
  - Stereo Vision
    - 3D human shape and size data
    - Incorporates appearance-based classifier
  - LADAR
- Multi-Sensor Tracker
  - Accepts from multiple sensor types
  - Correlates tracks
  - Predicts motion of humans for avoidance by Planners
- Integrated with On Road Planner for experimentation
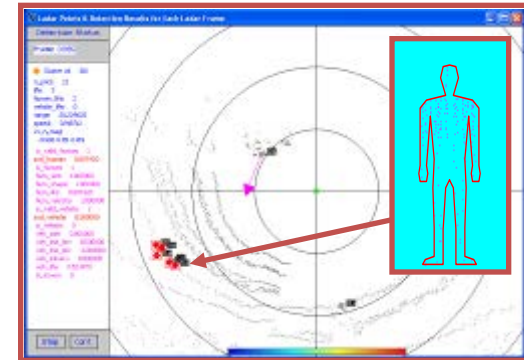
- Vehicle Detection/Tracking/Avoidance is another key item for the enhanced experiment
- Multiple Sensors
  - LADAR
    - This technology is transitioned from TARDEC SafeOps program
  - Stereo Vision
    - 3D vehicle shape and size data
    - Incorporates appearance-based classifier
- Multi-Sensor Tracker
  - Accepts from multiple sensor types
  - Correlates tracks
  - Road Planner predicts vehicle motion consistent with road network
- Integrated with On Road Planner for experimentation
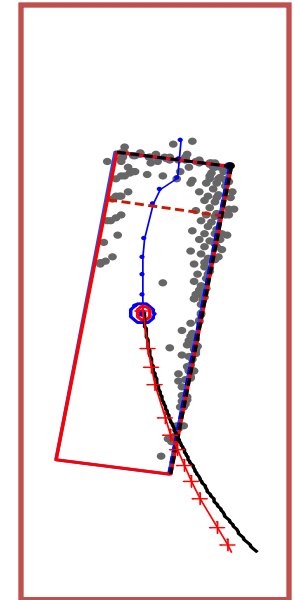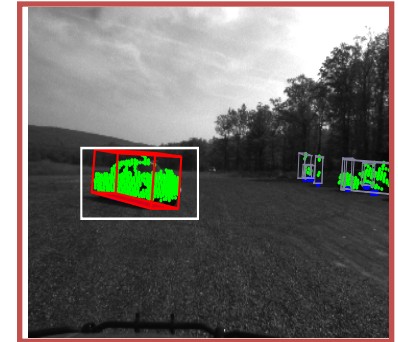
- Road Network Planner (Traffic Planner) was initially integrated for the SOURCE Baseline Experiment
- On Road Behavior
  - Appropriate behavior on roads is fundamentally different than for off road. Road Network Planner invokes this behavior.
  - Path and speed is regulated to avoid collisions with other detected moving vehicles
    - Except for passing, traffic immediately ahead of the vehicle is simply followed in a safe manner
  - Passing occurs only when a clear path of sufficient length exists to assure safe re-entry into a legal lane
  - Special planning is invoked avoid non-moving objects spotted in road lanes
  - Other basic rules of the road are followed
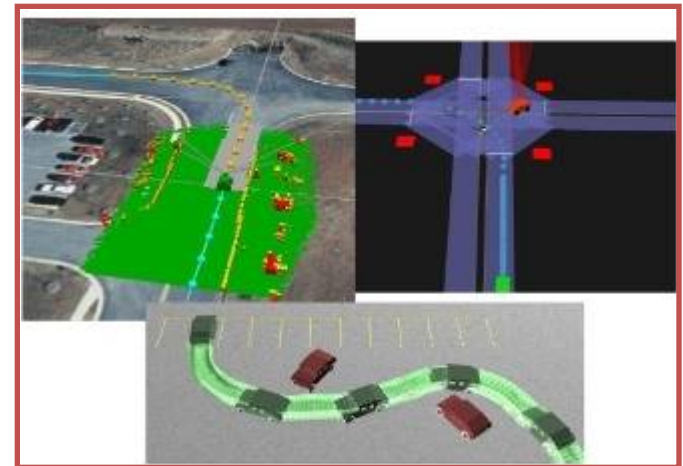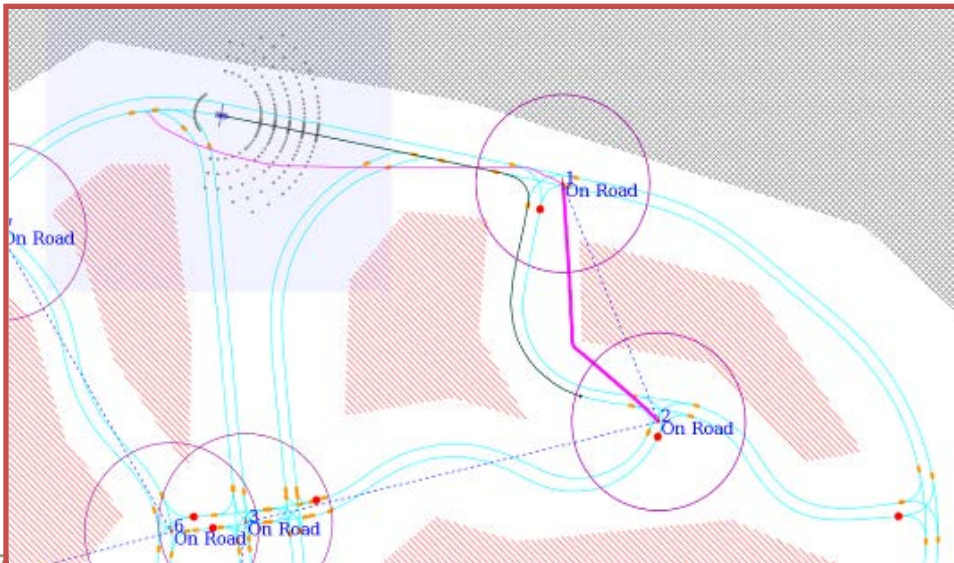
SafeOps-PROVEN ROAD NAVIGATION PLANNING IS NOW BEING INTEGRATED

- Registration To Prior Data allows improved navigation when prior data is available, even if GPS is poor
  - The core technology existed in leader follower technologies developed under several DoD programs (ANS, VTI, SafeOps). It was integrated with the Road Planner specifically for this SOURCE event
- Accurate positioning is determined by comparing what the robot "sees" with prior data
  - LADAR data (this experiment)
  - Road Edge visual perception (future)
  - Road Signs (future)
- This has improved performance in the MOUT site where GPS was frequently degraded

- Given the tighter quarters at Camp Lejeune MOUT site, as compared to our normal testing, plus operating a skid steer platform; this is an important improvement over the previous experiment
- This is critical for executing the core scenarios in this MOUT site
  - Autonomy system can take advantage of the APD vehicle's Skid Steer ability
  - This relies on precise navigation information provided by differential (RTK) GPS and/or Registration to Prior Data
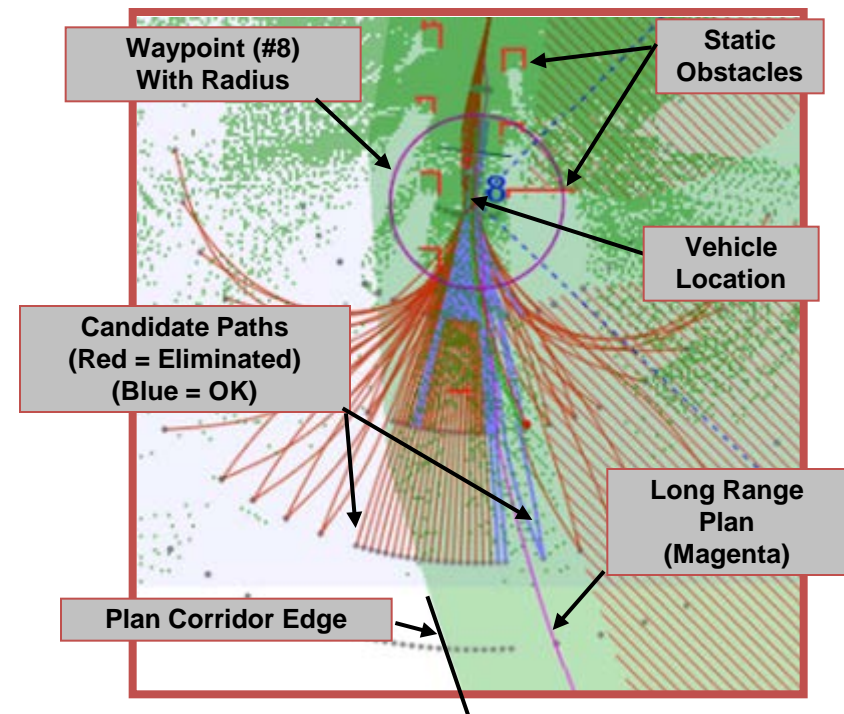
- The Camp Lejeune MOUT site includes a building overhang
- SOURCE includes logic for assessing whether the platform can fit under overhangs
  - Building walls that may otherwise be obstacles are classified as cover and assessed as passable space based on the size of the platform
  - The same functionality allows driving under tree cover and other terrain conditions
- This is an improvement over the SOURCE Baseline Event
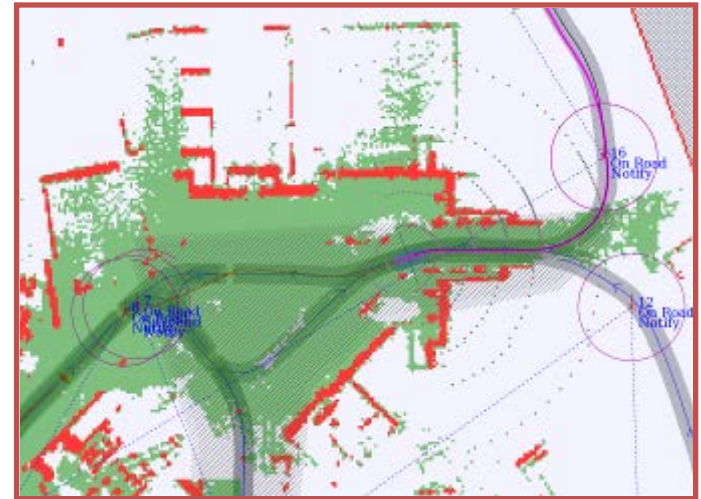
- This is a secondary item for the SOURCE experiment. In addition to the mannequins, other obstacles will be present.
  - This capability covers a wide range of static obstacles, such as signs, posts, trees/shrubs, barrel-like objects, stationary vehicles and buildings
  - Vehicle capabilities are taken into account in planning around static obstacles
- This capability has existed in SOURCE. Additional testing and integration with the new perception algorithms occurred in preparation for the Enhanced Experiment

Waypoint (#8) With Radius

Static Obstacles

Vehicle Location

Candidate Paths (Red = Eliminated) (Blue = OK)

Long Range Plan (Magenta)

Plan Corridor Edge

- **SOURCE Final Performance**
  - Complex urban and off-road terrain
  - Coordinated with IMOPAT

- **Camp Lejeune MOUT, w/Soldiers (October 2012)**
  - Two T2 Vehicles
    - Full ANS Version
    - Lower-Cost Version
  - Based on latest version of SOURCE enhanced ANS Software

- **Urban Terrain Testing Per CONOPS**
  - Complete Integrated Autonomous Capabilities
    - Automatic Transition Between On-road And Off-road Planning
  - Road Operation Functions on Complex Urban Terrain With Traffic
    - Basic Rules of the Road
  - Detection and Avoidance of Pedestrians and Vehicles at Required Speeds and Ranges
  - Dismount Operations in MOUT environment
    - Breadcrumb and Perception based following

- The Capstone Experiment, the third and final SOURCE experiment, is a data collection event intended to establish the capabilities of the ANS sensors vs Lower-Cost sensors and software integrated onto the T2 platforms.

- The Capstone Experiment grows on the capabilities established in the Enhanced Experiment.

- SOURCE Capstone Experiment shake out activities will take place from September 19th to September 28th, 2012 in Camp Lejeune, North Carolina.

- Official data collection for the experiment will be conducted in Camp Lejeune from October 1stth to October 19th, 2012.

- The official runs for record will be conducted utilizing both variants of the T2 platform (ANS / Lower-Cost)